



CBM+ and the CAMEO Project

Multi-program collaborative development of open source products for increased weapon system availability and reduced development and sustainment costs.

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Defining CBM+ and CAMEO

ALE vs. CBM vs. CBM+



Condition Based Maintenance (CBM)

- System of on-board sensors, self-monitoring systems, & off-board diagnostics that enable problem detection and maintenance only when needed

Common Components of CBM

Sensors-Ground Station-Data Management-
Engineering Analysis



Automated Logistics Environment (ALE)

- Enabling Infrastructure for executing CBM

Common Components of ALE

Data Stripping-Electronic debrief-Interactive
Electronic Technical Manuals (IETM)-Mx
Planning-Aircraft Status-Mx Information System
(MIS) Interfacing-Data Transfer-Lean Log.
Footprint-Certified Infrastructure



CBM+

•Collection

- Data from multiple sources (Aircraft, Mx, Ops, Supply, Training)

•Transmission

- Speed, Standardization, Structuring

•Warehousing

- Integrating different data from various sources into a single warehouse for mining

•Analysis

- Identify material/design defects
- Influence policy/procedure changes

•Action/Decision

- Mx/Ops/Training improvements
- Part /system re-engineering
- Safety/airworthiness determinations
- Supply optimization

Key Objectives of CBM+

Decrease Mx burden, Increase A/C availability & readiness, Enhance safety, Reduce life cycle costs

What is CBM+?



- **Condition Based Maintenance Plus(CBM+)**

- DoDI 4151.22

- “The application and integration of appropriate processes, technologies, and knowledge based capabilities to improve the reliability and maintenance effectiveness of DoD systems and components.”

Vision

- Establish predictive maintenance and anticipatory logistics through automated data collection, analysis, & integration

Objectives

- Decrease maintenance burden on the users
- Increase platform availability & readiness
- Enhance safety
- Reduce life cycle costs

Enablers

- Digital source collectors (embedded sensors, diagnostics, prognostics)
- Data warehousing
- Data fusion/analysis tools

What CAMEO Is and Isn't



➤ CAMEO is:

- An enabling infrastructure to facilitate cost-effective implementation of CBM+ and across a wide variety of DoD weapon systems
 - Initially developed by and for, but not restricted to, PMA-275
- An open source, government controlled project
 - Modular software development, with agile spiral planning
- An active collaboration between multiple weapon system programs
 - Shared development of common requirements while retaining flexibility to address program unique needs

➤ CAMEO isn't:

- On-board sensor and data recording system
 - Each program develops and installs on board systems to address their unique needs, using open APIs to allow CAMEO to communicate to/from the on-board systems
- A 100% solution for every program, but being 90% toward development path is a great place to start from cost, schedule, and performance perspectives
 - Many CAMEO capabilities are common or very similar between programs, but a limited amount of unique development and integration is required. Any unique development for one program may later be re-used by another collaborating program if it becomes applicable in the future



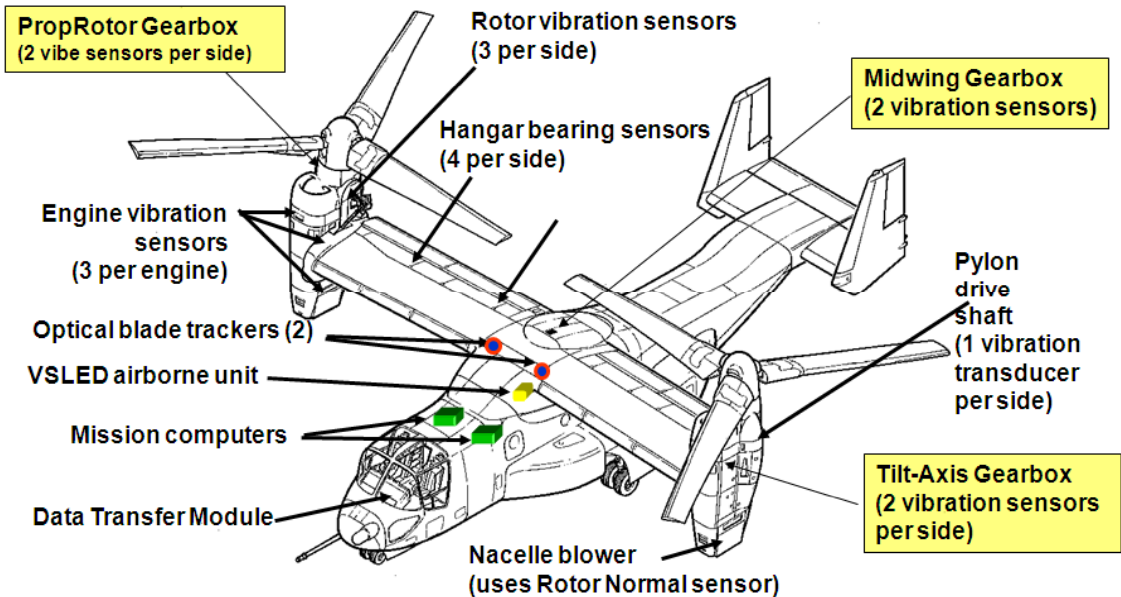
CBM+ and V-22

CBM for V-22



➤ The aircraft is already equipped for CBM

- Mx data (integrated avionics system Built-In-Test data)
- Dynamic component vibration data
- Engine vibration & performance data
 - Vibration (4 sensors per engine are tracked in 4 different modes)
 - Ground Nr 100%, Helicopter climb, Airplane cruise, Airplane fast
 - Performance (Each engine is tracked in 3 modes)
 - Climb out, Airplane cruise, Helicopter

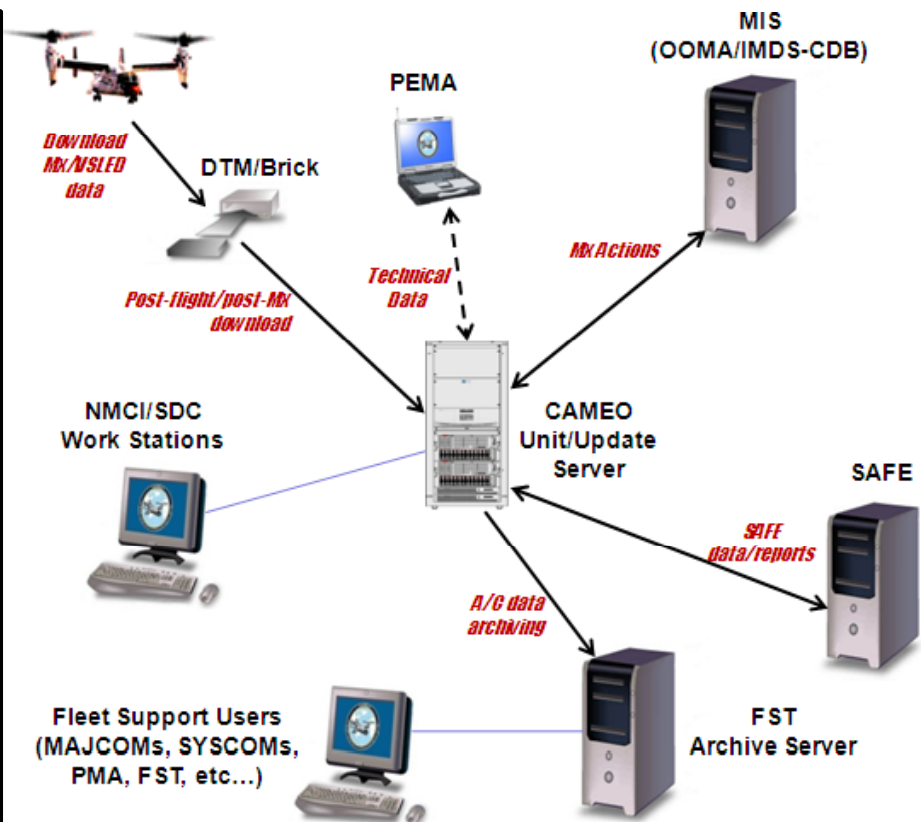


CAMEO enables CBM+ for V-22



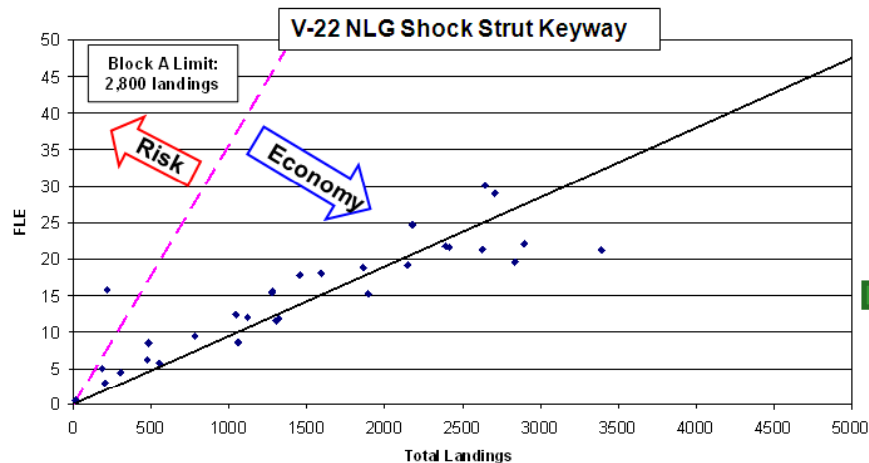
- **CAMEO is being utilized at all V-22 sites**

- Integral to post-flight debrief
- BIT review, trending, troubleshooting & analysis
- Dynamic Component & Engine vibration/usage monitoring, trending, & analysis
- Integrated with IETM
 - Integrated linking from Fault Code to Fault Isolation (FI) tasks
- Interfaces with OOMA/IMDS-CDB for Work Order creation
- Data automatically sent to FST archive at Cherry Point for engineering analysis
- Data will be auto-sent to SAFE server at Pax River for FLE calculation application
 - SAFE report generated and available to unit via CAMEO
 - FLE estimates sent from SAFE back to units & viewable via CAMEO for Mx decision/planning between official SAFE reports



CAMEO facilitates continuous integration & automation of operational, maintenance, and logistical processes to improve aircraft readiness and reduce sustainment costs for the war fighter community.

Fatigue Life Expended (FLE)



FLE Tracking via SAFE

- A/C data used to build regular SAFE reports
 - 1 component currently tracked will grow to over 85 tracked
 - Historically ~10% aircraft severely used – tracking prevents life limits from being exceeded to maintain safety of flight

Individual aircraft Fatigue Life Tracking via CAMEO

- Measures each aircraft against fatigue test article
- Accounts for differences in how each aircraft is flown
 - Majority of fleet aircraft fly less severely - tracking provides an economic benefit by allowing aircraft to fly longer than design life

Part Life Viewer: 1.0.71 - Microsoft Internet Explorer

Aircraft Id: 166485
 Mode: 00
 EPMIC Report: A1-V22AB-MRC-000
 Report Date: 2007-07-15
 Usage Report: OOMA/Nalcomis
 API Call Date: Mon Feb 02 2009

UNIS	Part Number	Serial Number	Nomenclature	Cage	Life Units Remaining	% Life Used	Tsn
6241010101	901-311-460-105	167	SLIP RING	97499	-84 Airframe Hour	100%	504
323101	901-380-501-103	079	PNEUMATIC RESERVOIR MODULE	77272	-2 Calendar Month	100%	30
549101	901-362-202-109	0017	LEFT UPPER COMPARTMENT COOLING BLOWER	97499	50.2 Airframe Hour	88%	369.0
321003	901-336-003-119	BEC-267	LEFT MAIN LANDING GEAR DRAG STRUT ACTUATOR ASSEMBLY	77272	415 Number of Landings	80%	2,585
549201	901-362-202-109	0110	RIGHT UPPER COMPARTMENT COOLING BLOWER	97499	69.2 Airframe Hour	79%	330.0
543112	901-060-637-101	00FC41	LEFT PROPELLER GEARBOX UPPER ATTACH STRUT ASSEMBLY	97499	205.2 Airframe Hour	76%	634.0
543117	901-033-238-101	00FC41	LEFT NACELLE FITTING ASSEMBLY AT STATION 342.3	97499	205.2 Airframe Hour	76%	634.0
543212	901-060-637-102	00FC42	RIGHT PROPELLER GEARBOX AND NACELLE SUPPORT STRUT ATTACH FITTING ASSEMBLY	97499	205.2 Airframe Hour	76%	634.0
543217	901-033-238-101	00FC42	RIGHT NACELLE FITTING ASSEMBLY AT STATION 342.3	97499	205.2 Airframe Hour	76%	634.0
21908K	TDV901-0302-101	FC4001	WATER SPRAY TUBE	77272	76 Airframe Hour	64%	134
321004	901-336-003-119	CP47-129	RIGHT MAIN LANDING GEAR DRAG STRUT ACTUATOR ASSEMBLY	77272	1,316 Number of Landings	50%	1,684

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Component life extensions reduces sustainment costs, spares posture, logistics footprint, MMH, etc...

Rotor Track and Balance Tool



- On going effort to improve RTB capabilities available to the V-22 maintainer
- Latest release of CAMEO provides improvements in the following areas:
 - RTB calculations
 - User Interface
 - RTB printing
- Additional improvements in work for next two CAMEO releases (3rd and 4th QTR 2011) and beyond

419 Episodes Evaluated Before 2010

5.8 Runs per Episode, 39.5 MMHR per Episode

41 Episodes Evaluated After 2010

3.5 Runs per Episode, 25.6 MMHR per Episode

Early 2011 Projections: Episodes/Year Forward

306 FCF Runs avoided per year
1893 RTB MMHR avoided per year

Electronic Troubleshooting Suite (ETS)



- **Improved utilization of aircraft BIT data**
 - Incorporate the breakdown and definition of Fault Words
- **Specifying the root cause**
 - Auto-correlating multiple BIT indications to identify common failure
- **Providing better visibility into integrated avionics system**
 - Functional schematics
 - Direct connectivity to MIPCU to download data to the PEMA
- **Intuitive user-interface for troubleshooting efficiency**
 - Troubleshooting flow diagrams, BIT definition
- **Identify/Notify trends prior to system/component failure**
 - Predictive fault detection (CF bearings, Hangar bearings)



Improved aircraft readiness, Reductions in CND/A799, MMH, MTTR, TARs, TPDRs

Information Capital



- **Collecting and leveraging mass amounts of data between organizations from multiple sources to provide wide-access availability of information and knowledge to multiple stake holders throughout the organization**
 - **Automated Statistical Data Mining**
 - Identifying trends or differences rapidly with large volumes of data
 - Focusing efforts of analysts and maintainers to review only data of potential interest
 - **Automated Reports/Metrics/Ad-hoc data queries**
 - Automating routine queries and facilitating new data query activities to reduce data handling requirements of a wide variety of data consumers
 - **Data Fusion/Visualization**
 - Integration of multiple data sources to provide a holistic view in a clear and concise manner based upon the various user disciplines

V-22 CAMEO – Current & Future Content



CAMEO 1.2.1.3- Currently Fielded

- Interface capabilities between ground station, IETM(Mx data, Troubleshooting, IPB, Schematics), OOMA, SAFE, & FST
- Electronic Troubleshooting Suite (ETS): Functional schematics, BIT to Fault Isolation automation
- BIT/Vibration/Engine trending & analysis
- Integrated Rotor Track & Balance Tool
- Work Center Manager/Readiness Dashboard
- Can be used on network or stand alone
- USMC, USAF network certified

CAMEO 1.2.2 – CY Q3 2011

- Part Life Viewer:
 - FLE fatigue life tracking and forecasting
- Advanced Capabilities for Maintenance Planning, Up Line Reporting, VDV, BIT Trending, Schedule Viewer, ETS enhancements
- Network compliancy, supportability enhancements, and compliant Web-based Architecture

CAMEO 2.0 - Notional CY Q4 2011

- JDRS integration
- Architecture refactoring and software updates
- Improved aircraft configuration views

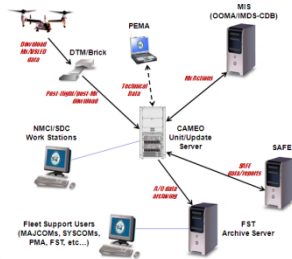
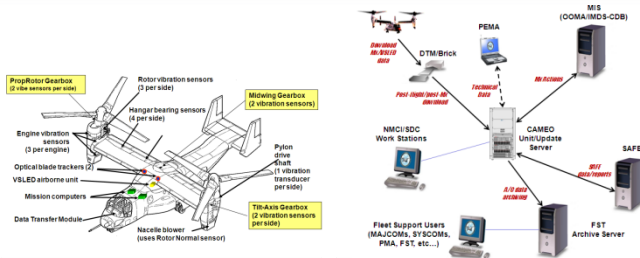
Future CAMEO Releases (2012-Beyond)

- Total Asset Visibility initiatives (UID/Rfid, 3M data integration)
- Information Capital capability toolset
 - Mx Data Reasoning, Data Mining capabilities
- CBM+ readiness improvements
 - FLE, Auto-reasoning, Prognostics, Electronic Periodic Maintenance Information Cards (E-PMIC)
- Increased Safety: MFOQA integration
- I and D level enhancements

SUMMARY



Condition Based Maintenance + Automated Logistics Environment =
CBM+



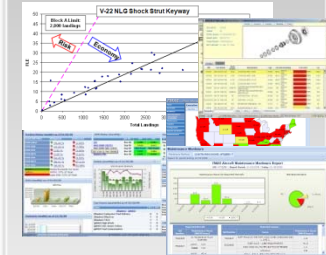
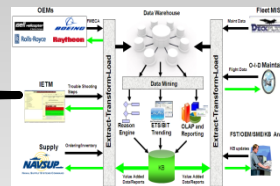
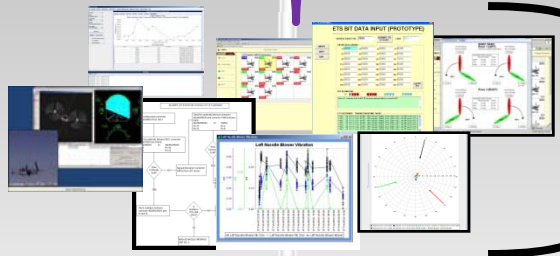
Collect

Transmit

Warehouse

Analysis

**Action/
Decision**



ENABLING INFRASTRUCTURE

- Data Collection
- Reactive Maintenance
- Time Based Inspection/Overhaul

DATA MINING/KNOWLEDGE MANAGEMENT

Knowledge Development
Fault Diagnosis
Remaining Useful Life Calculation
Inspection Targeting

INFORMATION CAPITAL

- Decision Support Toolsets
- Prognostics
- Proactive Maintenance
- On-Condition Inspection/Overhaul



CBM+ Collaboration

CAMEO Perspective



- **Open Source Software Development**
 - Prevents lock-in to single vendor and predatory pricing
 - Enables re-use of code/products and collaboration between programs
 - Government owns, but mix of government and contractors develop
- **Modular Capabilities for Flexible Re-use** (*Buffet line...*)
 - An active collaboration between multiple weapon system program
 - Shared development of common requirements while retaining flexibility to address program unique needs
 - Stovepipe/unique development is expensive
 - Common/rigid solution does not address user needs
 - ***One size does not fit all...*** But >80-90% of requirements are similar
- **Collaboration** (*Only be unique where needed*)
 - Share development costs for new/common capabilities
 - Minimize unique development for common needs
- **Solutions must be joint-focused** (*or at least service agnostic*)
 - Required for joint programs (V-22, JSF, etc.)
 - Enables/facilitates joint service collaboration, DoD level funding, FMS, etc.

Barriers to Collaboration



➤ **Barriers:**

- Lack of info/communication (unintentional stovepipes)
- Rice bowls/"not-invented-here" (intentional stovepipes)
- Proprietary development/IP (unable or costly to share capabilities)
- Service or platform focus (challenges to greater DoD efforts)
- Hardware or Operating System dependencies (rate of change)

➤ **Potential Enablers:**

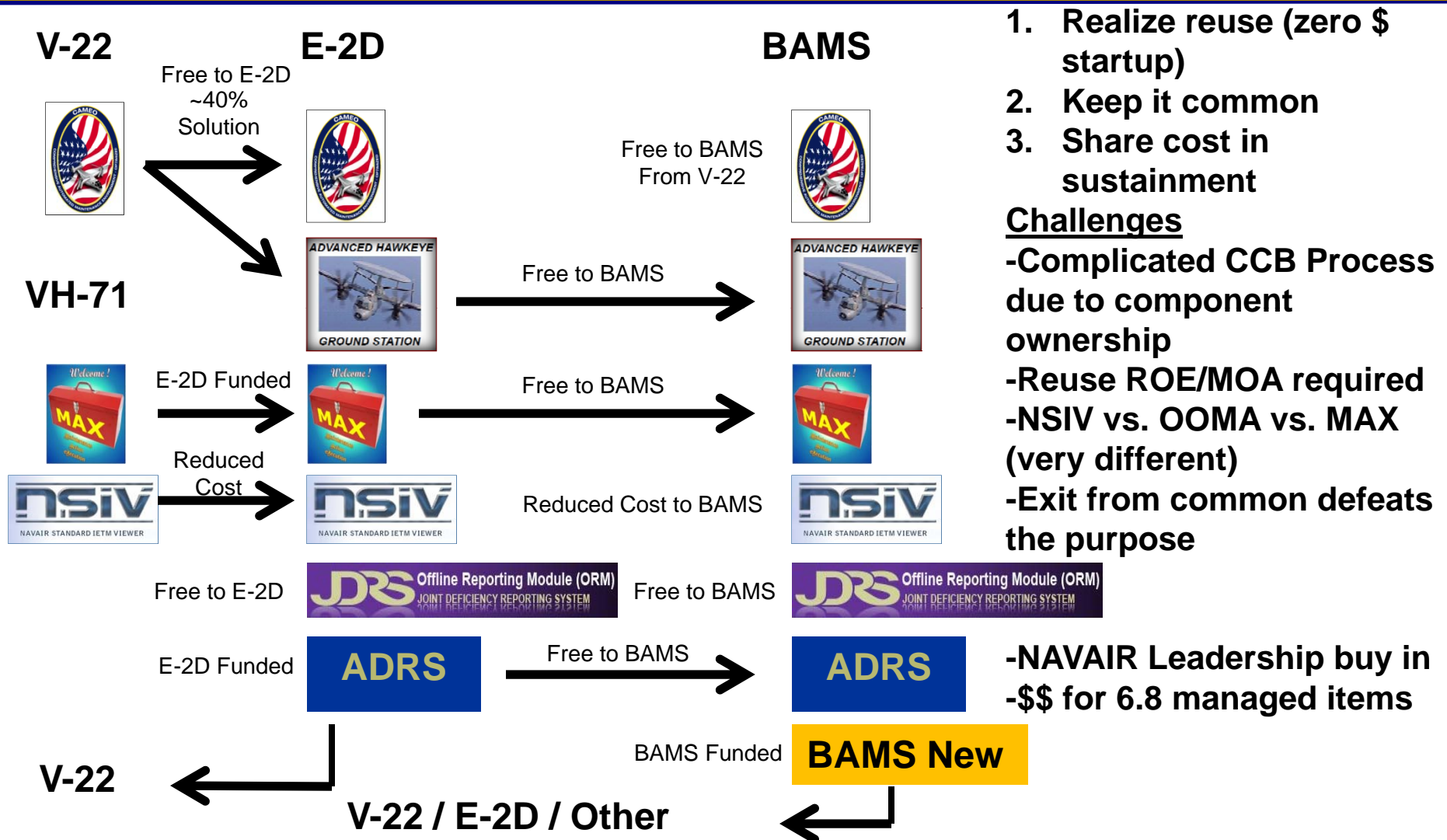
- Open source development - retain IP/data-rights from development
 - Enables re-use, sharing, and collaboration at minimal cost
 - Centralized funding for open-source development
 - For common as well as platform specific needs
 - Provide programmatic “speedbump” for proprietary development
 - Proprietary only for truly unique needs which cannot develop open solutions
-

Collaborative Partners



- **PMA-275 (MV-22 / CV-22 Osprey)**
 - Started original CAMEO development work to support V-22
 - Jointly developed by SSC-Pac and Bell/Boeing
 - SPAWARSYSCEN-Pac provides government technical support for PMA-275
 - To date, V-22 has borne most development and enhancement costs
- **PMA-231 (E-2D Advanced Hawkeye)**
 - Adapted some CAMEO capabilities to support short timeframe ALE/CBM+ capability requirements
 - Substituting a different IETM viewer module and customizing certain other components
- **PMA-262 (BAMS - Broad Area Maritime Surveillance)**
 - Currently exploring possibilities of adapting similar approach to E-2D, as they share a common OEM
 - Would be introducing real-time data connectivity requirements and solutions
 - Not currently required by, but of great interest to, the other programs
- **PMA-290 (P-8A Poseidon)**
 - Currently exploring possibilities of adopting Ground Station capabilities
 - MOA between PMAs in-work

Compounding Benefits of Reuse / Common



1. Realize reuse (zero \$ startup)
2. Keep it common
3. Share cost in sustainment

Challenges

- Complicated CCB Process due to component ownership
- Reuse ROE/MOA required
- NSIV vs. OOMA vs. MAX (very different)
- Exit from common defeats the purpose

- NAVAIR Leadership buy in
- \$ for 6.8 managed items

Multi-Service Collaboration Discussions



MARCORSYSCOM

- **Embedded Platform Logistics System (EPLS)**
 - Potential collaboration areas
 - BCA commonality
 - Data mining, analysis, visualization
 - Need to discuss other potential areas for collaboration



South Carolina Army National Guard (SCARNG)

- **CBM+ for AH-64 A/D, UH-60 A/L, CH-47D**
 - Potential collaboration areas
 - Collaboration with Univ. of South Carolina & SCARNG
 - BCA leveraging
 - Capability sharing

Future Collaboration



- **Current collaboration has been based upon a loose organization of like-minded individuals**
- **Cost and schedule benefits of adapting an already existing solution is clear and additional participation is anticipated**
- **As more participants join, a minimal amount of structure will need to be added to maintain smooth collaboration and alignment of efforts by larger numbers of organizations**
 - Establish an organization independent from the program offices to maintain the central repository of open source capabilities and coordinate a Configuration Control Board(CCB) to facilitate standard capabilities wherever possible
 - Establish more centralized funding to maintain momentum of open-source collaboration without undue influence from day to day priorities of program offices.
 - Funding to develop and sustain already exists in programs, but doesn't currently have a centralized focus

POCs / Questions



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BACK UP SLIDES

Additional Partnering



➤ **CBM+**

- OOMA/Deckplate
- IMDS-CDB/REMIS/ECSS
- SAFE, MFOQA

➤ **Current/Potential Partners**

- ALE
 - NFSA
 - Event Based Mx (EBM)
 - POMx
 - JDRS
 - JTDI
 - milSuite
- FMS

Data Mining & Analysis



Carderock Division

CBM Data Collection & Analysis

- Data mining and analysis techniques
- Deckplate analysis



Vehicle Level Reasoning System

- Diagnostic reasoning tools
- Intersystem failure recognition
- Event sequence graphing

Academia



Data Mining

- Massive-scale data streaming capabilities
- Pattern detection/predictive capability development
- Data structure exploitation



CBM Research & Analysis

- Drive train component & system testing
- Cost Benefit Analysis (CBA) development & modeling
- Natural language toolkits (processing, standardization)



Advance Research Lab: Complex System Monitoring

- Health management system toolset
- Algorithm development
- Degradation detection

Benefits of Academia



- Provide focused skillsets at various institutions
- Cost efficient
- Employ cutting edge techniques/capabilities through research
- Free up our own resources to focus on other aspects
- Provide a fresh, unbiased perspective

Potential Areas of Collaboration



➤ Academia

- Standardizing maintenance terminology
 - Natural language toolkits, lexicons, standardized documentation
- Large-scale Data Screening & Ad-hoc queries
 - Maintenance Actions
 - BIT data
 - Vibration and Engine Usage data
- Real time on-board sensor monitoring
- Real time vibe monitoring/energy harvesting
- Data fusion